Reanalyses in Weather/Climate and Toward Integrated Reanalysis for Earth Systems

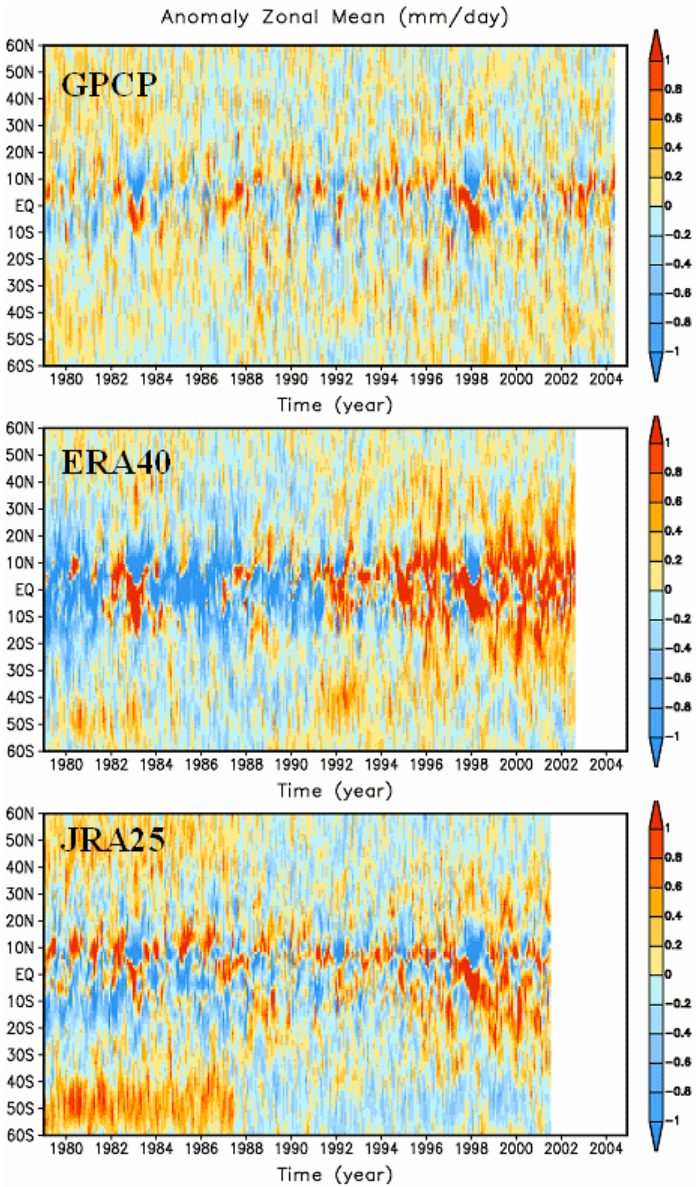
GEOS5-MERRA System Config.

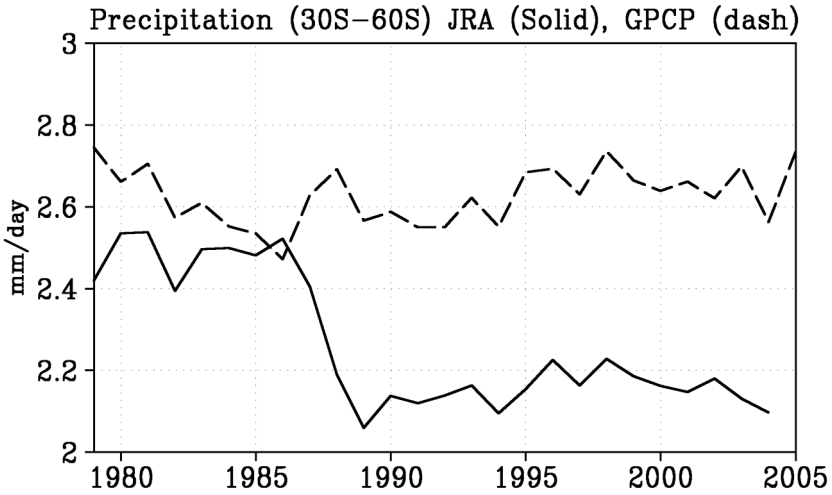
- Satellite Era, 1979 – Present
- ½°×⅔° Spatial resolution (lat-lon grid)
- 72 layers to 1 Pa
- 3 Streams (1979, 1989, 1998)
- Output Data
  - 3D Analysis (eta, prs), 6 hourly, ½°
  - 3D Diags, prs, 3 hourly, 1.25°
  - 2D Sfc, Vert Int, Land, **1 hourly**, ½°
  - Monthly, Monthly Diurnal, Climate Diags
  - 1.25° Coarse Resolution subset
- http://gmao.gsfc.nasa.gov/merra/

NASA and Reanalysis

- How to best integrate NASA remotely sensed data into Climate studies?
  - Is the best representation of the current state (e.g., using all of the obs.) the best analysis for climate?
- Challenges for climate reanalysis
  - The discontinuities presented by a changing observing system in data assimilation
  - Climate Model Bias
  - Uncertainty in Reanalysis
- Analysis of the Earth as a System for Climate studies:
  - Currently analyses for separate components conducted independently (e.g. Land or Ocean, using “Best” Forcing)
  - For balances, exchanges, etc, need to have consistent analyses of the separate components

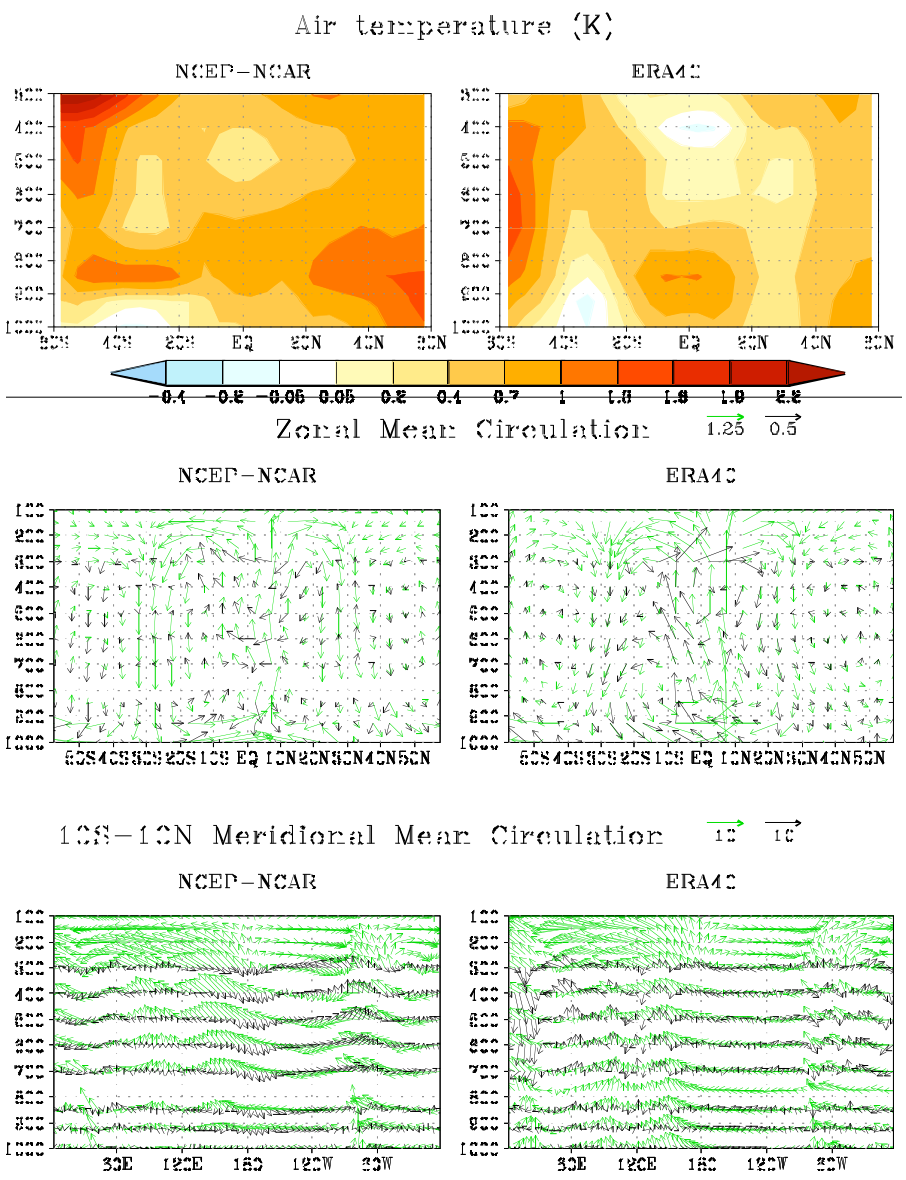
Discontinuities and Trends





- ERA40 TPW is realistic, dry model bias leads to large P trend
- JRA25 has a smaller tropical trend with severe discontinuity in the extratropics

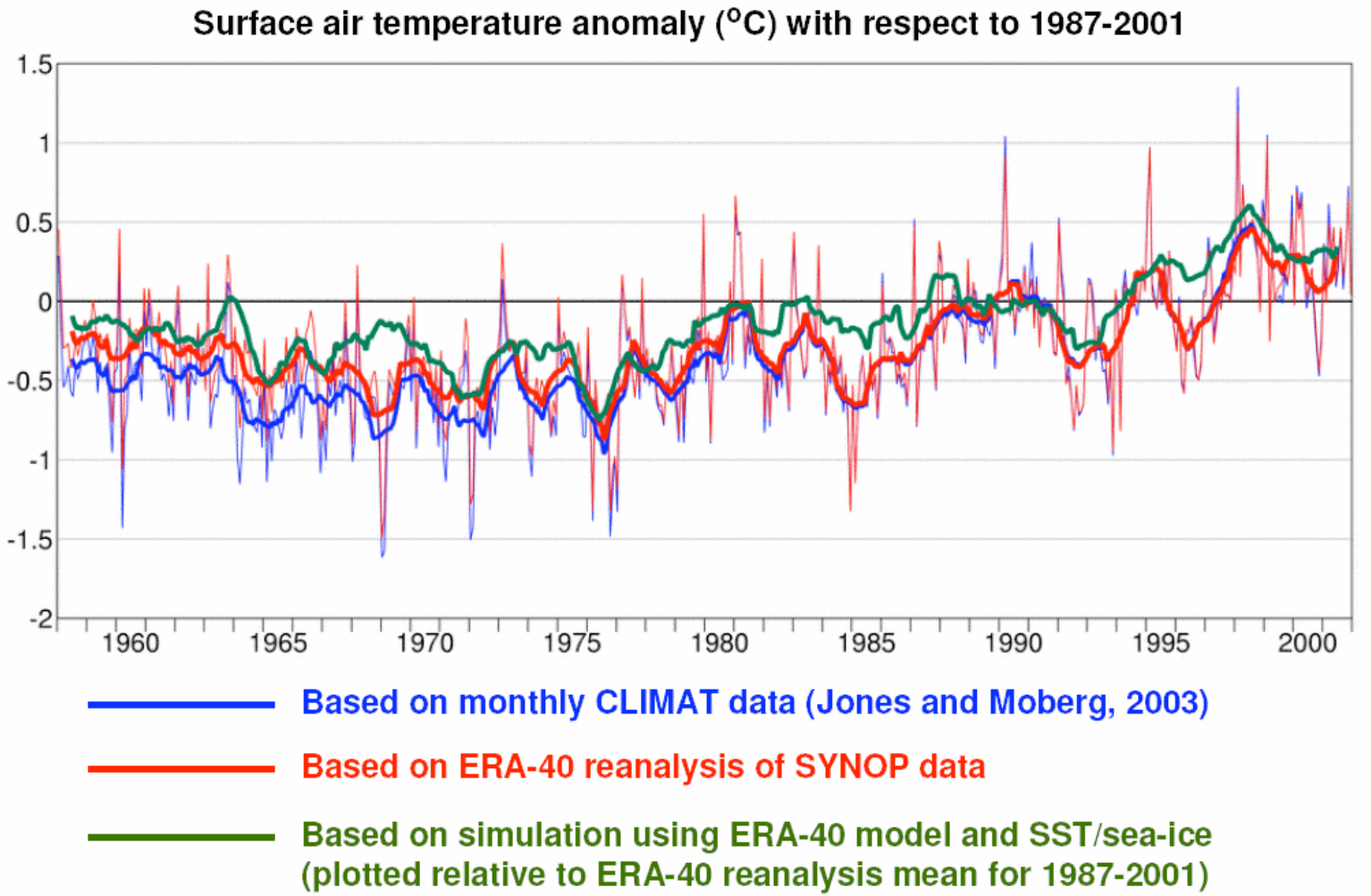
Reanalysis Trend Differences



- Atmosphere Temp trends warming, with different structure
- Intensification in the Walker and Hadley circulations differ between reanalyses

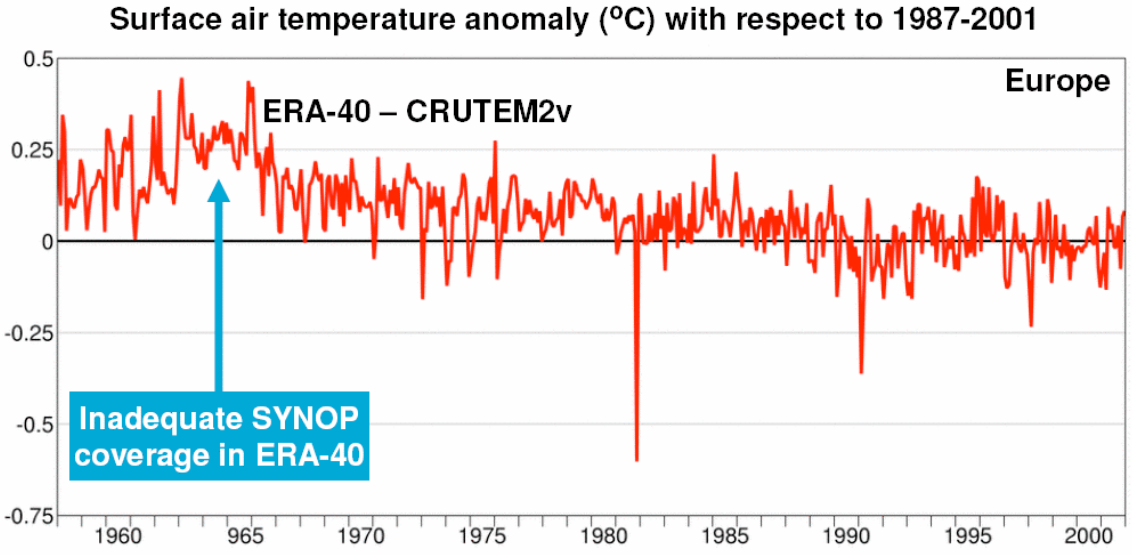
Chen et al (2007, submitted)

ERA40 Compared to Surface Stations (NH)

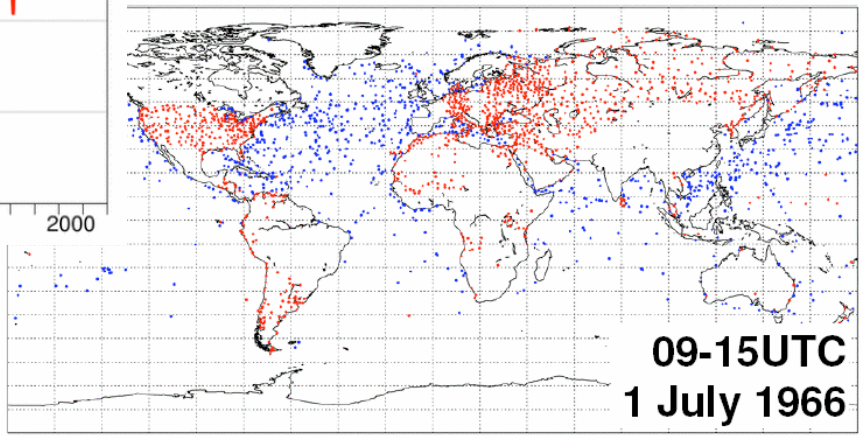


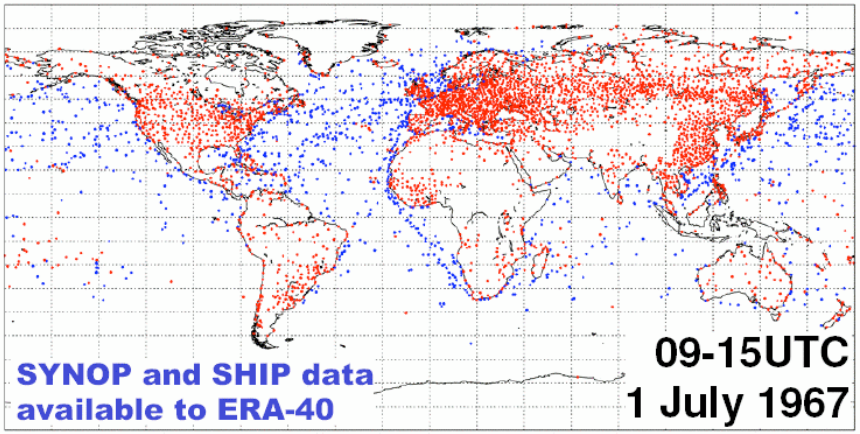
Simmons et al. (2004), Courtesy Dick Dee, ECMWF

Number of Observations



Simmons et al. 2004
Courtesy Dick Dee, ECMWF

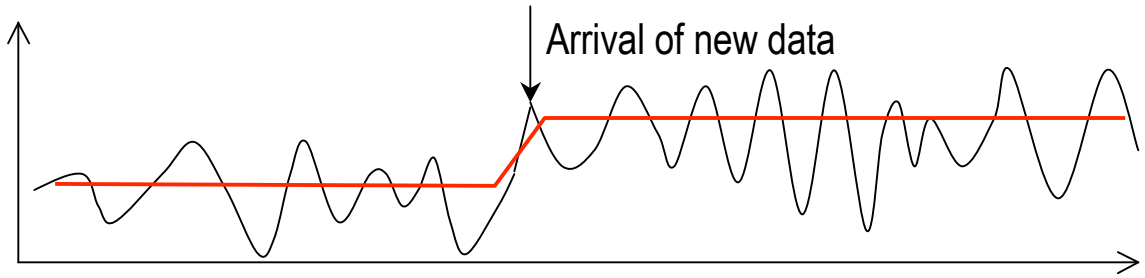


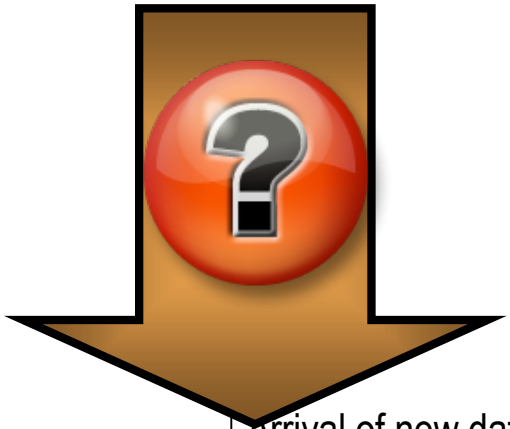


- New data becomes available in 1967 for ERA 40 input.
- Satellite era input data likely helps sfc temps

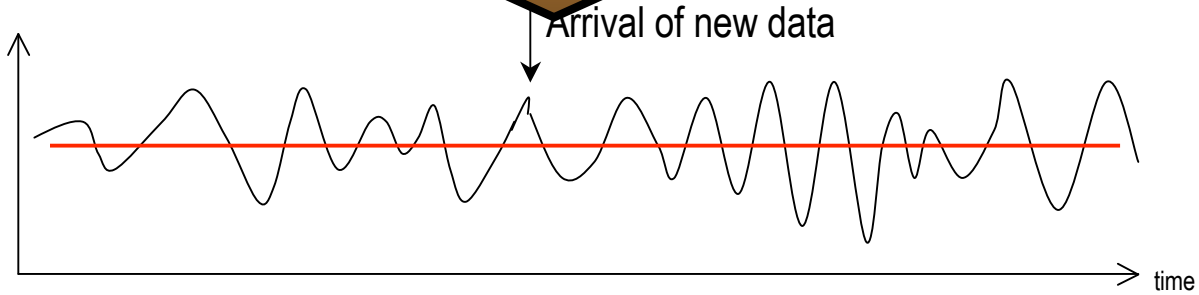
Climate Model Bias Correction

Analysis with a Biased Model





Analysis with an Unbiased Model



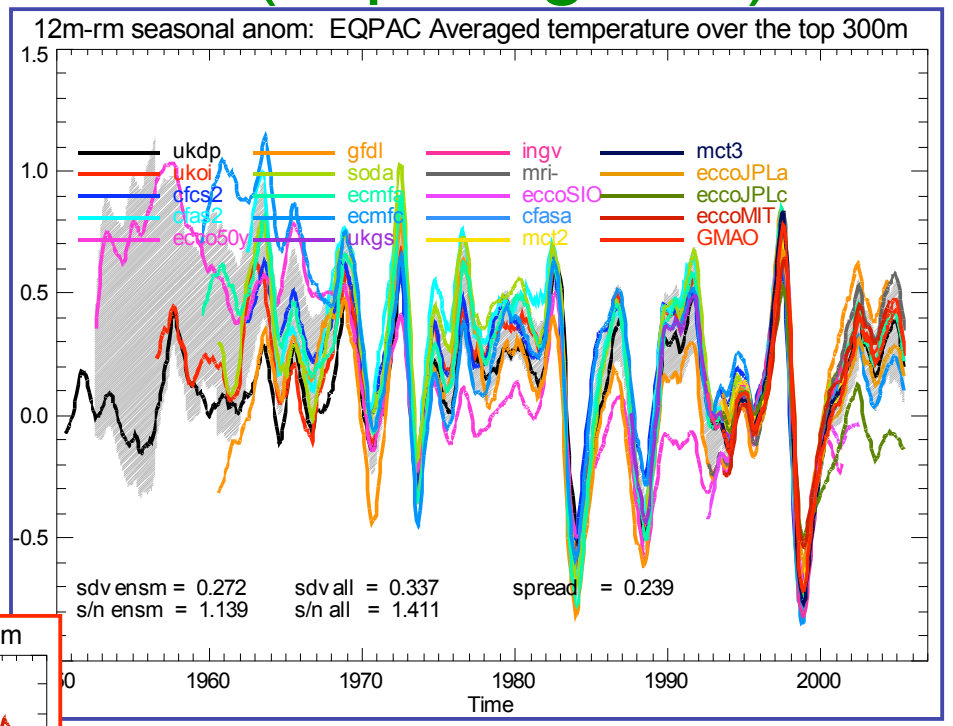
Land Reanalysis

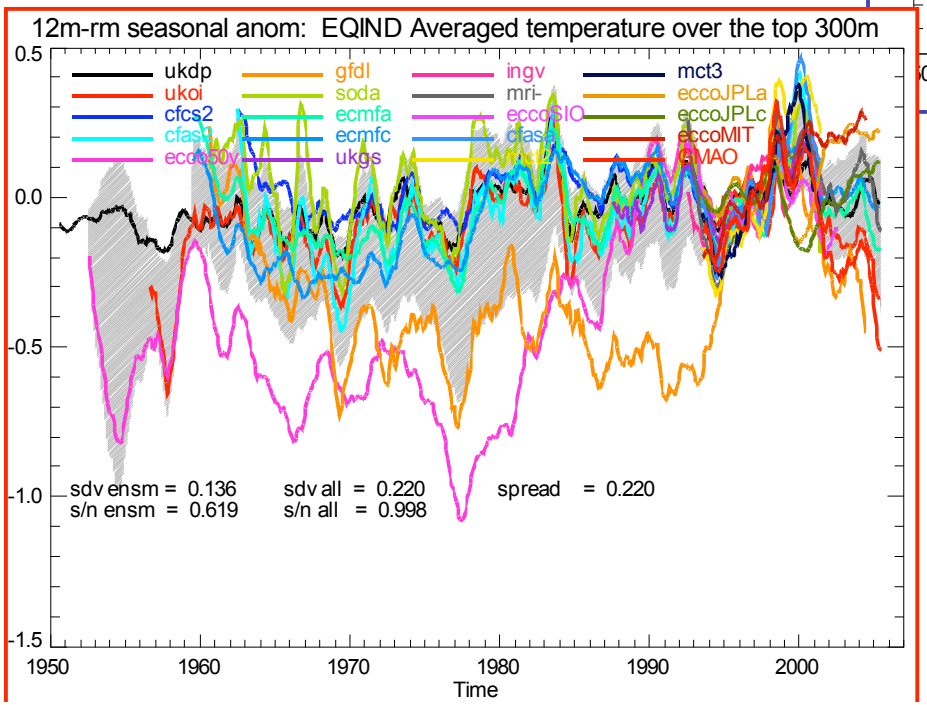
- ERA40 – Station meteorology analysis
- GLDAS – Offline land forcing (fluxes and met), generally not assimilating states, but using several land models (Rodell et al. 2004)
- Soil water, surface temperature, snow water all being researched (Offline – Rodell, Coupled – Reichle) for global products
- Satellite Data issues
  - Soil moisture gaps – SMMR(78-87), AMSRE (02 on), TRMM (1997 on) – Reichle et al. (2006)
  - Surface Temp requires diurnal cycle – heterogeneity and bias corrections
  - Snow water – AVHRR, SSMI data since 1980 quality of the retrievals is relatively poor

Ocean Reanalyses: T300 (Eq. Regions)

From CLIVAR/GODAE workshop at ECMWF 2006
courtesy Balmaseda & Weaver

- **Eq Pac: Uncertainty decreases with time.**
- **Relatively robust interannual variability.**
- **Increased uncertainty after 2000. Why?**





- **Eq Indian: Uncertainty remains large throughout the record.**
- **Signal to noise <1. Outliers**
- **This is also the case for the Eq Atlantic**

Ocean Color Analyses for Climate - the issue of consistency

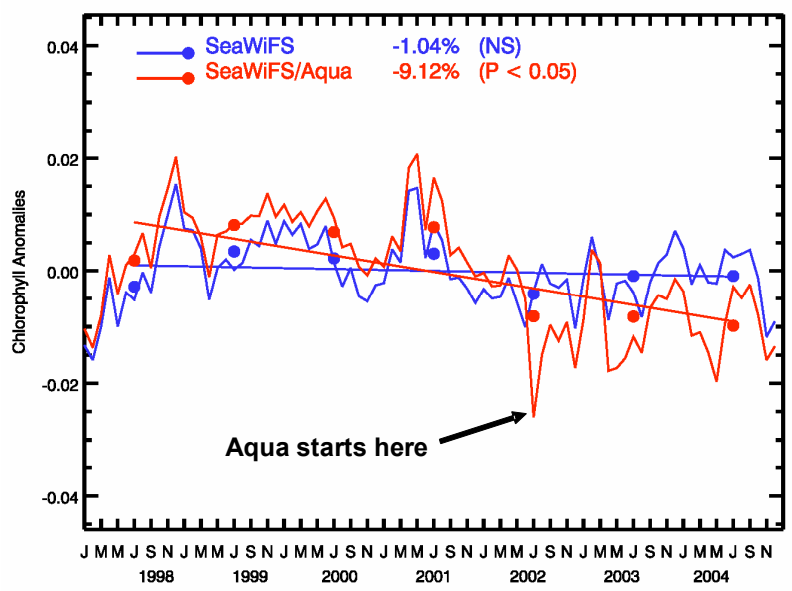


Figure 2. Chlorophyll anomalies and trends for SeaWiFS (blue line), and a time series of SeaWiFS and MODIS-Aqua, with MODIS replacing SeaWiFS when it became available in late 2002 (red line). The colored dots indicate the global annual mean; the line is monthly mean. The trend for SeaWiFS is negligible. The SeaWiFS-Aqua trend is negative and statistically significant. The entire record is changed because the climatology is different when using MODIS, and it changes the anomalies.

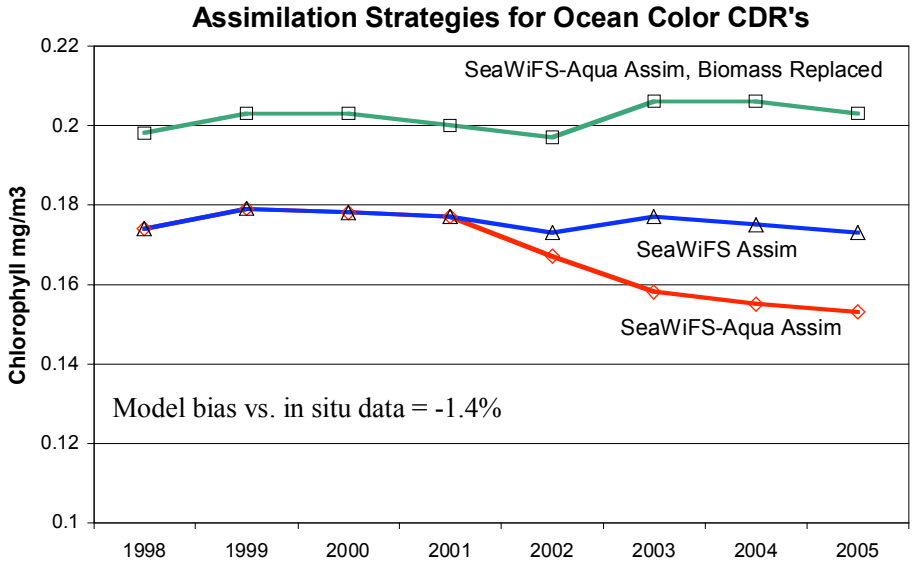
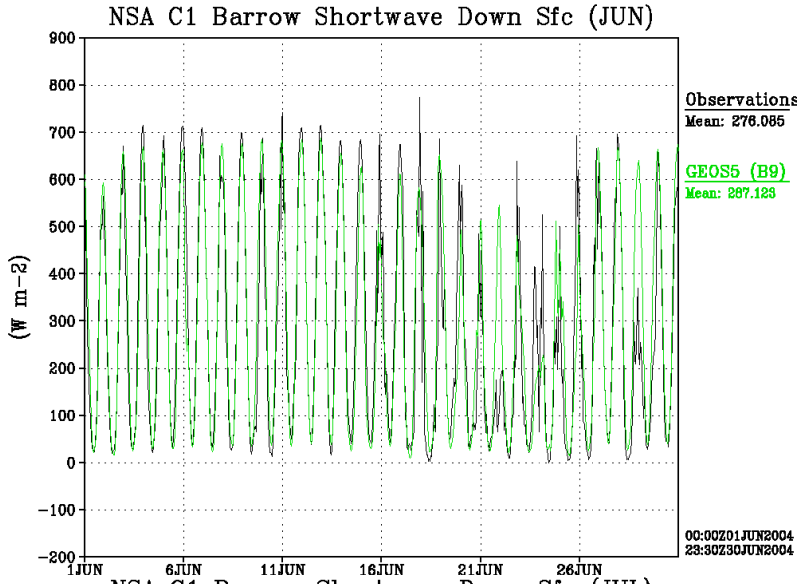
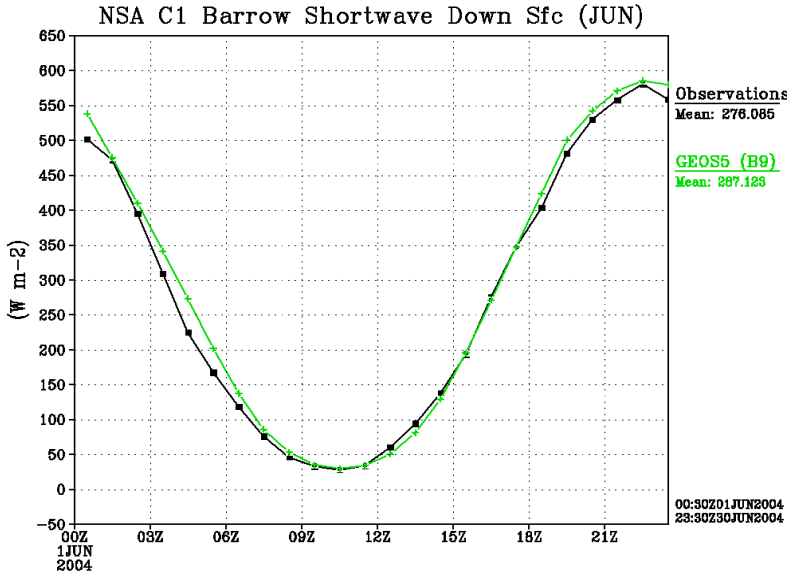


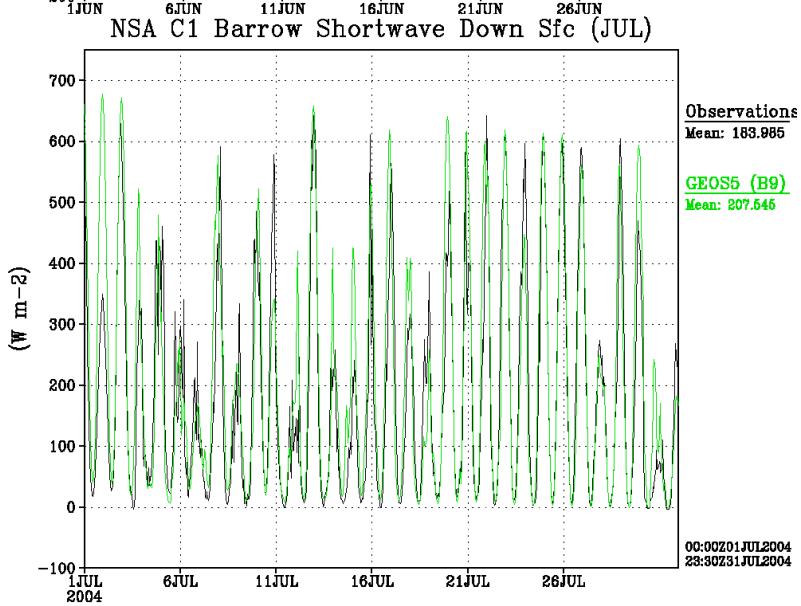
Figure 5. Trends derived from assimilation of SeaWiFS chlorophyll data (blue line), the SeaWiFS-MODIS-Aqua combination, where MODIS-Aqua replaces SeaWiFS in Sep 2002 (red line), and the bias-corrected assimilation of the SeaWiFS-MODIS-Aqua combination, where the global biomass of the satellite chlorophyll is divided out and replaced by the biomass of the model. The bias-corrected assimilation produces a chlorophyll trend that is statistically indistinguishable from the SeaWiFS assimilation. But the bias-corrected assimilation has higher global estimates of chlorophyll.

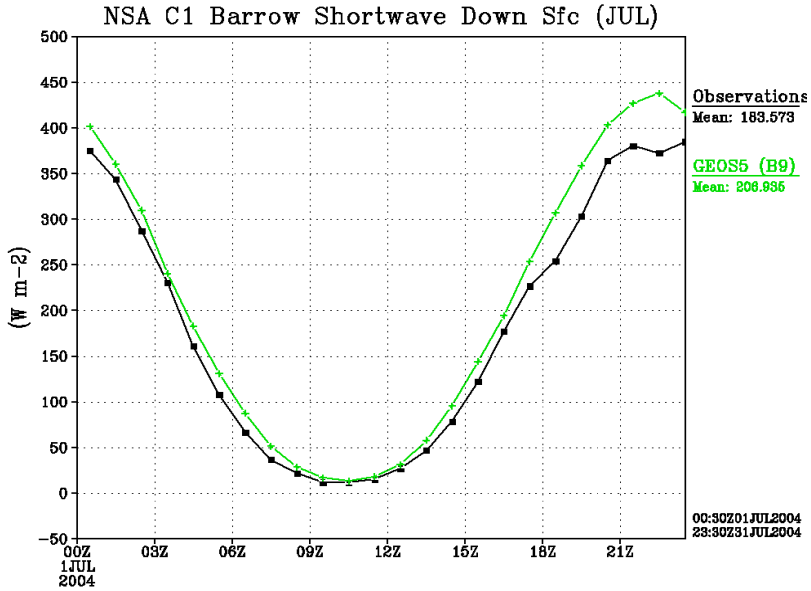
Courtesy Watson Gregg

GEOS5 Barrow, Jun/Jul 2004





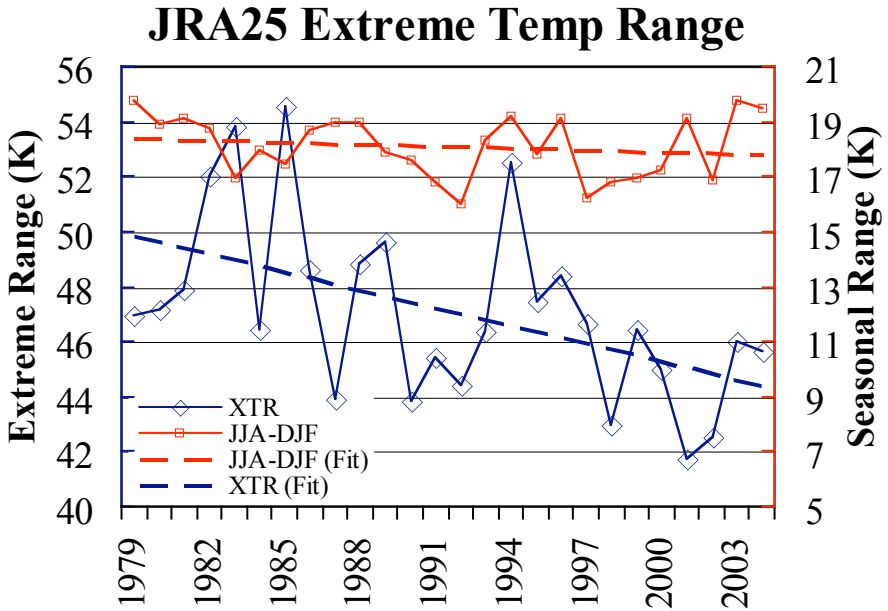




Uncertainty in Reanalyses

- Observation Inter-calibration and Homogenization
- Increments and Forecast Error
- Multi-Model evaluations (ongoing, poster)
  - 4 long reanalyses, many operational analyses
  - Observation signal should be retained in an ensemble
- Ensemble of an analysis system
  - Perturbations will affect the down stream analyses; Saturation provides some uncertainty
- Observing Systems Experiments (OSE)
  - Test the impact of entire observing systems in **reanalyses** (e.g. SSMI, AIRS) to evaluate discontinuities and trends

Extreme Diagnostics: Linking Weather and Climate



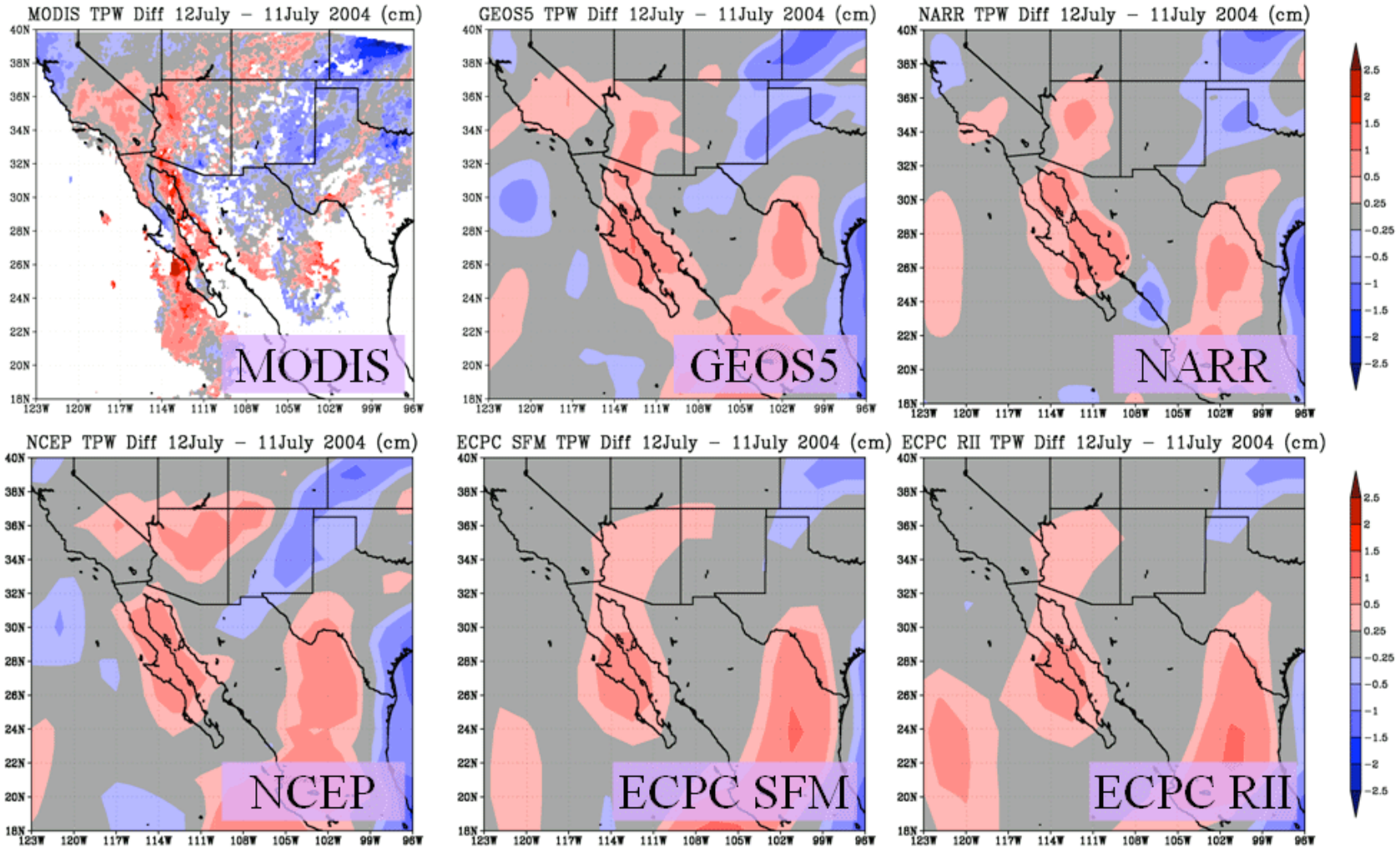
Northeastern United States area average Extreme Temperature Range (XTR, highest minus lowest daily temperature each year) and seasonal mean temperature difference (DJF minus JJA). Winter temperatures are slightly warming (not statistically significant), but there is a significant (p-value <0.01) decrease in the range of extreme temperatures.

- Tebaldi et al (2006)
- Evaluated IPCC Scenarios
  - Extreme temperature range
  - Growing season length
  - Frost days
  - Heat wave duration
  - Warm nights
  - Consecutive dry days
  - Number of heavy rain days
  - Maximum 5 day total precipitation
  - Precipitation intensity index
  - Number of rain days >95th percentile

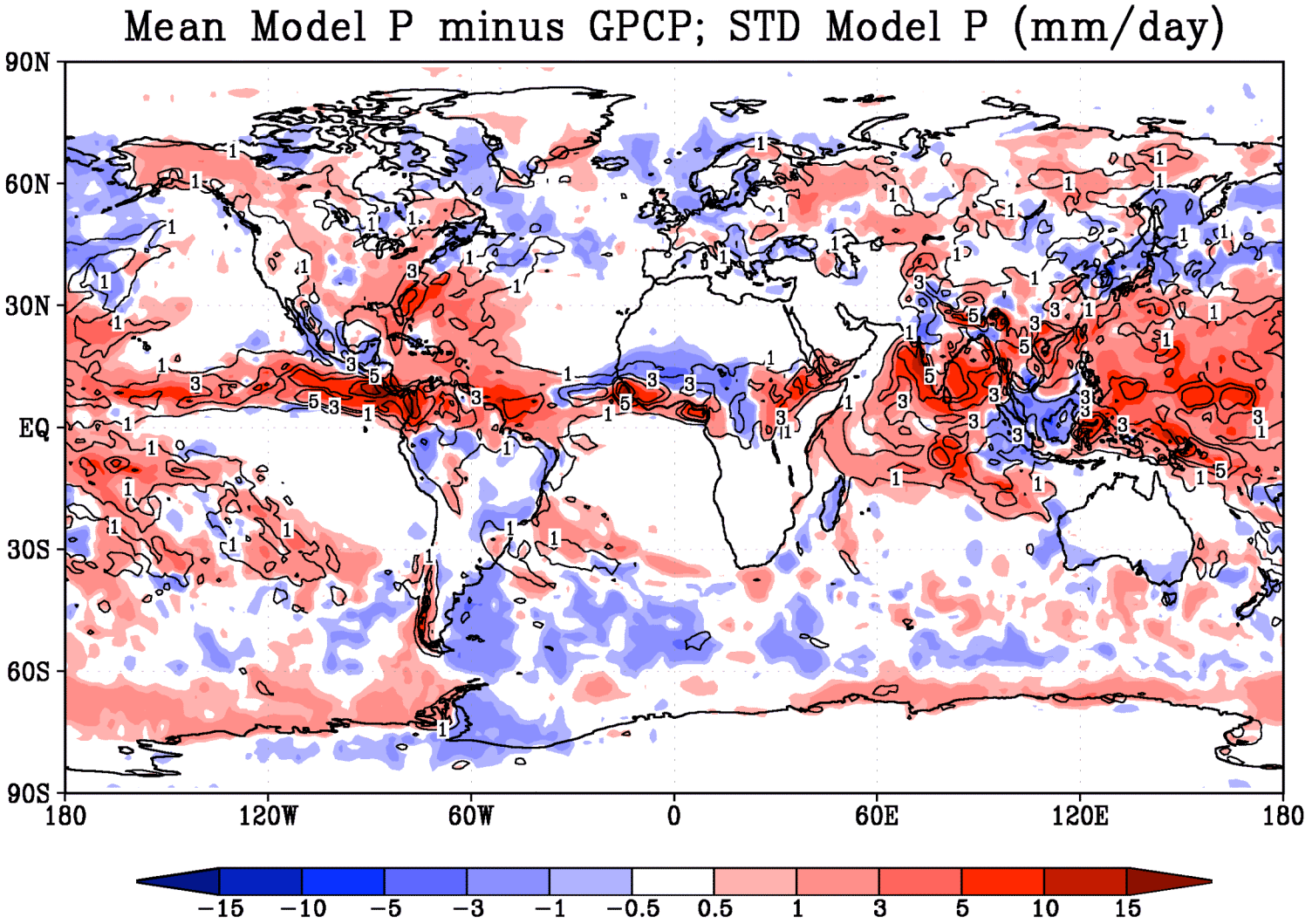
Thanks!

(backup slides follow)

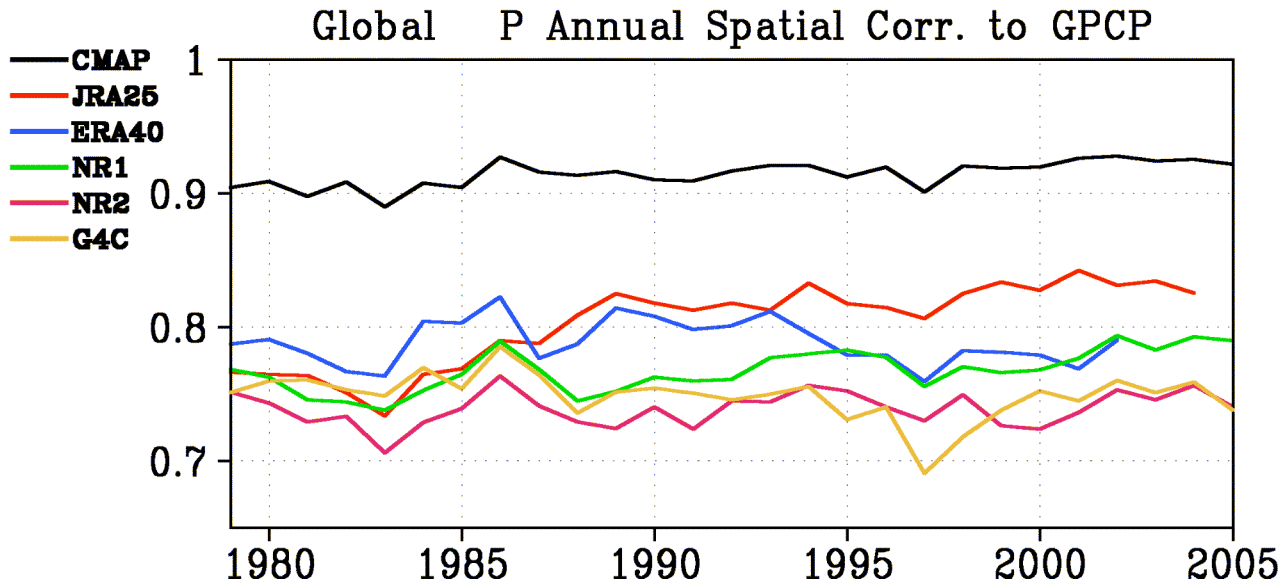
Moisture Surge during NAME 2004



Uncertainty in Analyses



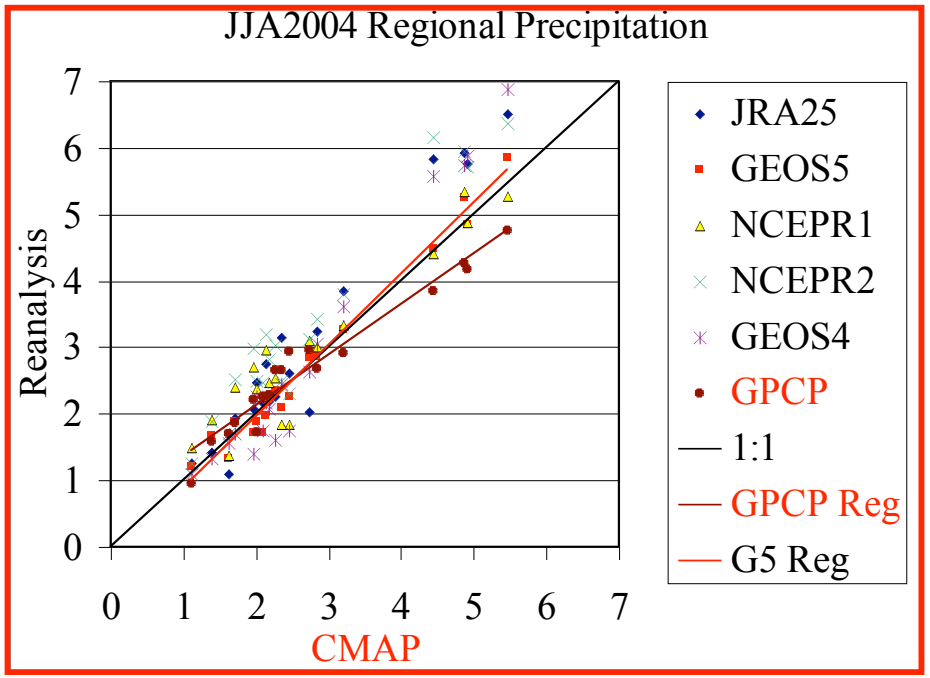
Improving Physical Fields



- May also mean that reanalyses need to be executed and iterated more frequently than the present rate

GEOS5 Development: JJA 2004

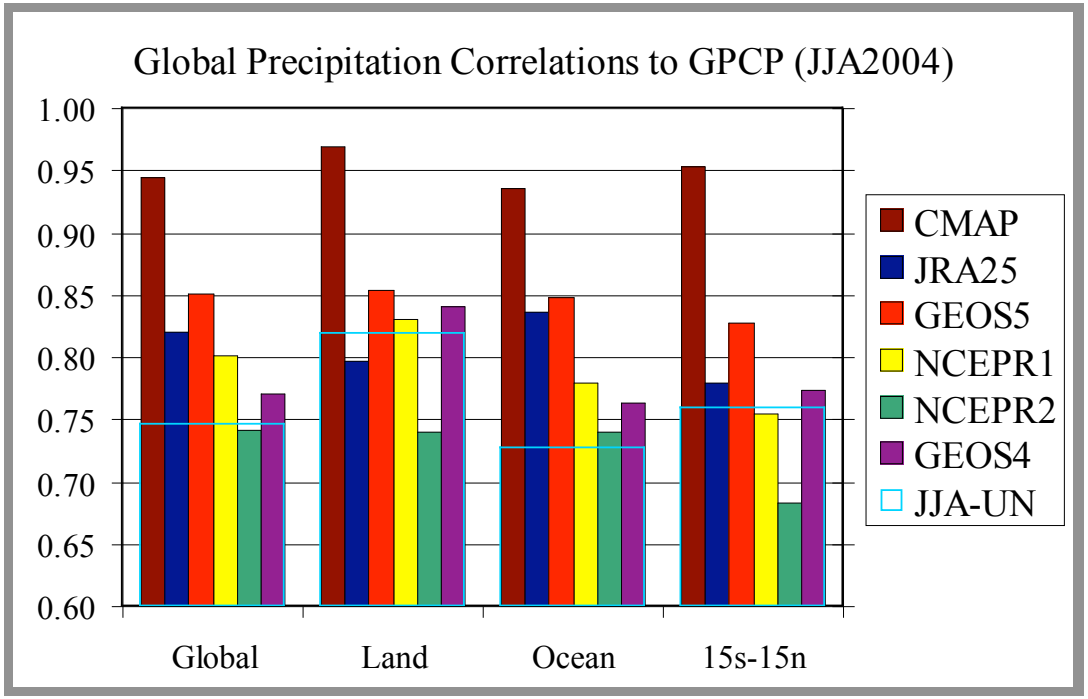
- Reanalyses biases are high in the tropics and scattered elsewhere
- CMAP Regression line is tilted off 1:1 compared with GPCP
- GEOS5 appears closer to CMAP



Regional average precipitation from 19 large scale oceanic and continental regions as well as global averages. The red line is the GEOS5 fit to GPCP, and the brown line is the CMAP fit.

GEOS5 Development: JJA 2004

- Spatial correlation of monthly P for global regions
- GPCP and CMAP have high land correlation
- Reanalyses need improvements especially over land and tropics
- New experiments underway

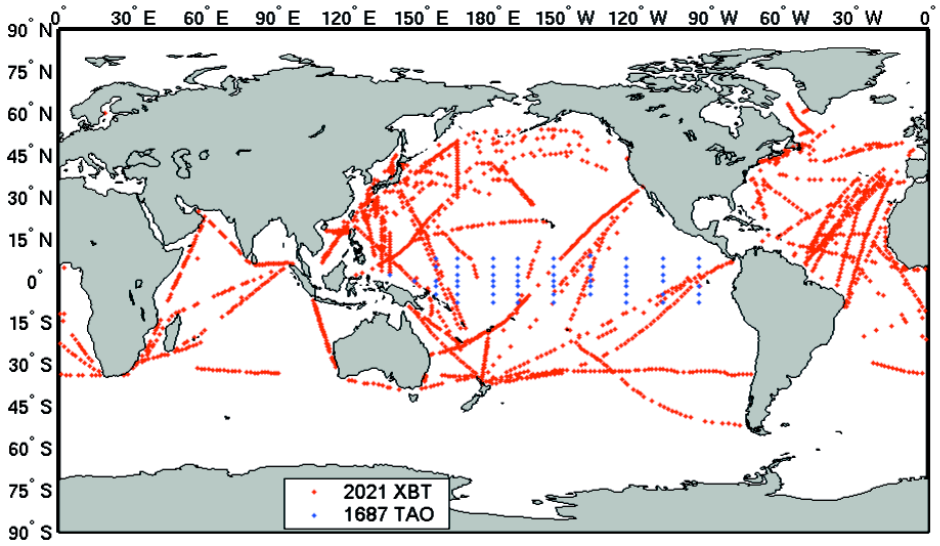


Spatial correlation of the Reanalyses systems to GPCP. The CMAP correlation (brown bar) shows the maximum expected correlation considering their uncertainties. The blue line is the average random correlation between unmatched months, a minimum of correlation.

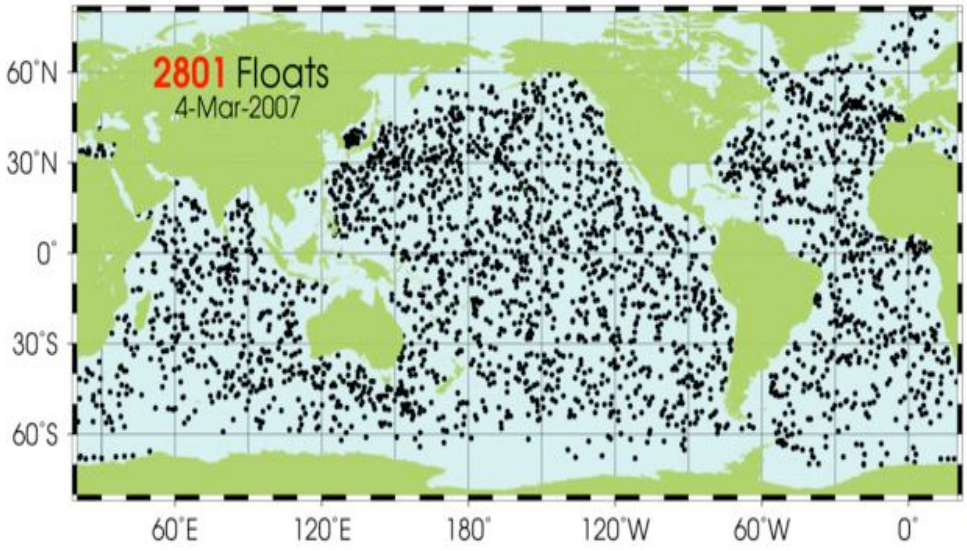
Ocean re-analyses

- Several groups undertaking historical reanalyses
  - Scientific investigations of climate variability (CLIVAR)
  - Initial conditions for decadal prediction (e.g., Hadley Centre and collaborators in ENACT: ENhAnced ocean data assimilation and ClimaTe prediction)
  - Initial conditions for seasonal forecasts/hindcasts
- Challenge: Ocean is data-poor prior to 1993 (Topex-Poseidon, completion of TAO, Implementation of Argo program in ~2001)
- Challenge: Surface forcing products have large uncertainties/errors, particularly precipitation
- Challenge: Few observations below 750 m (Argo is changing that)
- Comparison of products at 2006 CLIVAR/GSOP Workshop at ECMWF
  - revealed a wide range in the analyses
  - some with poor comparisons with assimilated observations
  - a variety of techniques - OI, 3DVAR, reduced-state Kalman filter; 4DVAR, EnKF
- Issues: QC'd observation stream; observational error characteristics (esp. representativeness); forcing errors; background covariance models (esp. near-surface); multivariate corrections (salinity and currents are important, use of satellite observations); providing analysis uncertainties

XBT and TAO profile locations for June 1997



Argo profiles February 2007



Issues in land reanalysis:

GMAO **off-line** land data assimilation development for soil moisture (mature enough for reanalysis), skin temperature (in progress), and snow (in progress).

Coupling of GMAO off-line EnKF-based land assimilation system to GEOS-5 GCM/GSI (atm. DA) in progress (not funded thus very slow).

Feedback of land assimilation on atmosphere only possible in coupled system!

Data issues:

Data gap for satellite soil moisture: retrievals ready from SMMR (1978-87) and AMSR-E (since 2002). Potential for retrievals from TRMM (since 1997) and ERS-1/2(1991-present with gaps), but not ready for reanalysis.

Skin temperature retrievals from ISCCP (multi-sensor, multi-platform, since ~1980) and MODIS (since 1999) have been used in pilot assimilation studies. A complete reanalysis requires understanding the temporal consistency, across years and across the diurnal cycle, in particular of ISCCP data. Model and observation bias issues not fully resolved.

Snow water equivalent retrievals: available since ~1980 (mostly SSM/I and AVHRR). Quality of retrievals relatively poor, more off-line testing and development needed.